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MINATION

(NASA-CR-170889) RESULTS OF VARIABLE ENTHALPY TESTS OF CPR-488 TIP PANELS IN MSFC HOT GAS FACILITY (Lockheed Missiles and Space Co.) 37 p HC A03/MF A01 CSCL 11D

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Lockheed
Missiles & Space Company, Inc
Huntsville Research & Engineering Center
Cummings Research Park
4800 Bradford Drive
Huntsville, AL 35807

RESULTS OF VARIABLE ENTHALPY TESTS OF CPR-488 'TIP' PANELS IN MSFC HOT GAS FACILITY

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Marshall Space Flight Center, AL 35812

by

W. G. Dean

APPROVED C. Donald Andrews

C. Donald Andrews, Manager
Systems Engineering Section

FOREWORD

This work was performed by personnel in the Systems Engineering Section of Lockheed's Huntsville Research & Engineering Center for NASA-Marshall Space Flight Center under Contract NAS8-32982.

The MSFC technical monitor for this study is Mr. W. P. Baker, EP44.

BACKGROUND AND INTRODUCTION

The Space Shuttle External Tank (ET) is covered with CPR-488 spray foam. This foam serves two purposes: (1) to provide cryogenic insulation on the tank while the vehicle is on the pad and in flight, and (2) protect the aluminum skin from aerodynamic and radiative heating during ascent. In-flight pictures taken of the ET after separation from the Orbiter indicated that the foam thickness/design was highly conservative. Part of this conservatism is because the foam recession design data were generated at an enthalpy level which was at or near the maximum value to be experienced during flight. This peak value lasts only for a short time during flight. One would expect the foam recession rate to be less at lower enthalpy levels because of the reduction in foam surface temperatures. Since most of the trajectory time is spent at the lower enthalpy levels, while the design data were taken at higher levels, the resulting total recession during flight should be less than the values predicted from the data. It would therefore be desirable to generate data at these lower enthalpy levels to determine just what effect enthalpy has on the foam performance/recession.

Another problem on the ET foam is that of being able to determine the flight CPR-488 foam recession. Since the ET is not recovered, this must be done without any physical thickness measurement. One idea for making the measurement is to imbed foam plugs of various thicknesses in the original CPR-488 foam. These foam plugs would be made of BX-250 foam which has a different (white) color from the CPR-488 after it has been heated. These plugs would be visible in the photographs until the CPR-488 receded to the plug depth and then the plug would blow away and a recession depth could be identified. This assumes, of course, that the BX-250 and CPR-488 both receded at the same time rate. The photos would be made from the Shuttle Orbiter after ET separation. This idea was also incorporated into the tests which are documented herein.

TEST OBJECTIVES

The objectives of these tests were as follows:

- To determine the effects of variable enthalpy levels on CPR-488 foam performance/recession.
- To determine whether the BX-250 "thickness indicator plugs" (TIP) concept is feasible for measuring recession rates of CPR-488 foam during ET flight.

TEST PANEL DESCRIPTION

Six CPR-488 panels were built and tested in this series of tests. These were designated TIP-1 through TIP-4, and TIP-7 and TIP-8. Figure 1 shows a sketch of these panels with locations of thermocouples, BX-250 plugs and thickness measurements. Figures 2 through 7 show the pretest photographs of the six panels. The BX-250 plugs were all 2 in. in diameter and of various thicknesses. Figure 8 shows the TIP plug thickness values. TIP-7 and TIP-8 plugs had TiO_2 to make them whiter. Figure 9 shows the heating rate cal model used to calibrate the HGF for these particular tests. It consisted of an array of thin skin/thermocouple locations running horizontally and longitudinally along the HGF duct test section in Position 1.

TEST DESCRIPTION AND RESULTS

The enthalpy levels in the test region were determined from combustion chamber measurements determined in previous tests. The resulting recovery temperature and enthalpy values are shown in Table 1.

Table 1 also presents a summary of the foam/TPS runs. Eight runs were made, all in Position 1 of the HGF. Run times varied. The first two were 20 sec and subsequent runs were 35 sec. This increase was made after checking the total foam recession during the first two runs.

Results of the foam recession measurements are shown in Tables 2 through 7. These tables show pretest and post-test thicknesses, change in thickness, recession rate, heating rate, and ratio of total recession to total heat load. Data are given for both CPR-488 and BX-250.

Figure 10 shows a plot of recession rate versus heating rate for CPR-488. The high enthalpy data are in general higher in recession than the low enthalpy data.

A further effort was made to show the enthalpy effect. This was to compare the average value of R/Q, total recession over total heat load. These results are summarized as follows:

Run No.	Average R/Q_2 (Mil/Btu/ft^2)	Enthalpy Level	Average R/Q for All Runs
1000	1.72	High	Average of High Enthalpy Runs = 1.76
1001	1.90	High	
1002	1.76	High	
1003	1.66	High	
1004	1.05	Low	Average of Low Enthalpy Runs = 0.92
1005	0.79	Low	

Again, this form of the data shows higher recession at the higher enthalpy level than at the low enthalpy level.

A third method was also tried in an effort to show the enthalpy effect. In this method a comparison was made between the peak values of recession at the two enthalpy levels. Straight lines were drawn through the approximate peak points for each enthalpy level on Fig. 10. Using values read from these peak lines, the cross plots of Figs. 11 through 14 were made. These plots show recession rate versus recovery temperature (i.e., enthalpy). Figure 11 is for a constant heating rate of 4 Btu/ft^2-sec. Figures 12, 13 and 14 are for constant heating rates of 6, 10 and 15 Btu/ft^2-sec, respectively. This form of the data shows a definite trend of the recession with enthalpy. Also shown on these figures for comparison are data from some AEDC tests. These data were taken at approximately 1420 F recovery temeperature. Also one data point is available at a recovery temperature of 1100 F. As seen on these figures, the agreement with the HGF data is reasonably good.

Figures 15 through 20 show the post-test photos of all TIP panels. Inspection of these photos and post-test inspection of the panels showed that the BX-250 TIP plugs receded to about the same depth as the CPR-488. The BX-250 plugs without TiO_2 charred and changed to about the same color as the CPR-488 in most cases. However, it was still obvious when a plug was completely gone. The BX-250 plugs which had TiO_2 gave a more distinct appearance of the plugs and is a better design (see Figs. 17 and 19 of TIP-7 and TIP-8). Figure 20 (Test 1004, TIP-3) has a different appearance from the rest of the panels. The panel is a much lighter color due to removal of most of the char. A review of the movies indicated that this occurred during a rough shutdown of the HGF.

The temperature rise on the aluminum substructures of these panels did not exceed 6 F on any panel.

CONCLUSIONS

The following conclusions have been made from these tests:

- The TIP plug idea works. The accuracy of the indicated recession depth is approximately ±1/16 in. This is a good concept.
- The BX-250 plugs with TiO_2 work better than the regular BX-250.
- There is an effect of enthalpy on CPR-488 foam performance.

Table 1

SUMMARY OF FOAM/TPS RUNS

Run No.	Model No.	Enthalpy Level	Recovery Enthalpy Value (Btu/lb)	Recovery Temp(F)	Run Time (sec)	Pos. in HGF Duct
1000	TIP-1	High	511	1668	20	1
1001	TIP-7	High	511	1668	20	1
1002	TIP-2	High	511	1668	35	1
1003	TIP-8	High	511	1668	35	1
1004	TIP-3	Low	451	1420	35	1
1005	TIP-4	Low	451	1420	35	1

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Table 2

RECESSION DATA FROM TEST 1000

CALCULATION OR DATA SHEET PAGE 1 OF

SERIAL NO. TIP-1
TEST 1000 - 11/9/81
POS. 1 - 22.03 Sec.

RECOVERY ENTHALPY - 511 Btu/lb
RECOVERY TEMPERATURE - 1668°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT^2-SEC)	R/Q MIL/BTU-FT^2		
CPR-488	1	1165	897	268	12.17	4.6	2.67		
	2	1175	918	257	11.67	4.6	2.54		
	3	1140	883	257	11.67	4.7	2.48		
	4	1065	840	225	10.21	6.2	1.65		
	6	1180	925	255	11.58	6.4	1.80		
	8	1270	990	280	12.71	6.4	1.99		
	9	1220	933	287	13.03	6.4	2.04		
	10	1065	850	215	9.76	10.2	0.96		
	11	1125	830	295	13.39	10.0	1.34		
	12	1220	925	295	13.39	6.8	1.97		
	13	1065	900	165	7.49	5.5	1.50		
	14	1330	1053	277	12.57	4.5	2.79		
	15	1075	798	277	12.57	11.5	1.09		
	AVER.	1161	903	258	11.71	6.8	1.72		
BX-250	5*	1090	675	415	18.84	6.8			
	7*	1100	530	570	25.87	12.0			
	16*	1060	520	540	24.51	7.0			
	17*	1095	675	420	19.06	7.0			
	18*	1095	800	295	13.39	7.0			
	19*	1035	300	735	33.36	11.0			
	20*	1090	620	470	21.33	11.5			
	21	1055	650	405	18.38	10.5			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

Table 3

RECESSION DATA FROM TEST 1001

CALCULATION OR DATA SHEET PAGE 3 OF

SERIAL NO. TIP-7
TEST 1001 - 11/9/81
POS. 1 - 20.09 Sec.

RECOVERY ENTHALPY - 511 Btu/lb
RECOVERY TEMPERATURE - 1668°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT²-SEC)	R/Q MIL/BTU-FT²		
CPR-488	1	1225	977	248	12.34	4.6	2.68		
	2	1365	1042	323	16.08	4.6	3.50		
	3	1240	1020	220	10.95	4.7	2.33		
	4	1200	994	206	10.25	6.2	1.65		
	6	1390	1041	349	17.37	6.4	2.71		
	8	1410	1127	283	14.09	6.4	2.19		
	9	1415	1140	275	13.69	6.4	2.14		
	10	1210	935	275	13.69	10.2	1.34		
	11	1100	1048	52	2.59	10.0	.26		
	12	1450	1070	380	18.91	6.8	2.78		
	13	1235	1020	215	10.70	5.5	1.95		
	14	1385	1147	238	11.85	4.5	2.63		
	15	1240	929	311	15.48	11.5	1.35		
	AVER.	1297	1038	259	12.89	6.8	1.90		
BX-250	5*	1290	850	440	21.90	6.8			
	7*	1210	800	410	20.41	12.0			
	16*	1290	790	500	24.89	7.0			
	17*	1265	865	400	19.91	7.0			
	18	1265	860	405	20.16	7.0			
	19*	1255	620	635	31.61	11.0			
	20*	1265	800	465	23.15	11.5			
	21	1215	835	380	18.91	10.5			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

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Table 4

RECESSION DATA FROM TEST 1002

CALCULATION OR DATA SHEET PAGE OF

SERIAL NO. TIP-2
TEST 1002 - 11/10/81
POS. 1 - 35.04 Sec.

RECOVERY ENTHALPY - 511 Btu/lb
RECOVERY TEMPERATURE - 1668°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT²-SEC)	R/Q MIL/BTU-FT2		
CPR-488	1	1045	638	407	11.62	4.6	2.52		
	2	1065	635	430	12.27	4.6	2 67		
	3	1030	725	305	8.70	4.7	1.85		
	4	1130	780	350	9.99	6.2	1.61		
	6	1145	695	450	12.84	6.4	2.01		
	8	1170	740	430	12.27	6.4	1.92		
	9	1170	875	295	8.42	6.4	1.32		
	10	1045	535	510	14.55	10.2	1.43		
	11	1110	550	560	15.98	10.0	1.60		
	12	1075	765	310	8.85	6.8	1.30		
	13	1055	729	326	9.30	5.5	1.69		
	14	1110	663	447	12.76	4.5	2.77		
	15	1140	525	615	17.55	11.5	1.52		
	AVER.	1100	681	419	11.96	6.8	1.76		
BX-250	5*	1140	630	510	14.55	6.8			
	7	1105	295	810	23.12	12.0			
	16*	1185	450	735	20.98	7.0			
	17*	1185	670	515	14.70	7.0			
	18	1130	720	410	11.70	7.0			
	19*	1075	220	855	24.40	11.0			
	20	1080	39u	690	19.69	11.5			
	21	1070	330	690	19.69	10.5			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

Table 5

RECESSION DATA FROM TEST 1003

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CALCULATION OR DATA SHEET PAGE OF

SERIAL NO. TIP-8
TEST 1003 - 11/10/81
POS. 1 - 35.05 Sec.

RECOVERY ENTHALPY - 511 Btu/lb
RECOVERY TEMPERATURE - 1668°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT²-SEC)	R/Q MIL/BTU-FT2		
CPR-488	1	980	720	260	7.42	4.6	1.61		
	2	925	626	299	8.53	4.6	1.85		
	3	995	740	255	7.28	4.7	1.55		
	4	1010	743	267	7.62	6.2	1.23		
	6	930	579	351	10.01	6.4	1.56		
	8	1445	757	688	19.63	6.4	3.07		
	9	1030	800	230	6.56	6.4	1.03		
	10	1105	368	737	21.02	10.2	2.06		
	11	1020	420	600	17.12	10.0	1.71		
	12	1040	713	327	9.33	6.8	1.37		
	13	1075	792	283	8.07	5.5	1.47		
	14	895	580	315	8.99	4.5	1.99		
	15	1000	484	516	14.72	11.5	1.28		
	AVER.	1035	640	395	11.27	6.8	1.66		
BX-250	5*	1065	590	475	13.56	6.8			
	7	1025	410	615	17.55	12.0			
	16*	1090	545	545	15.55	7.0			
	17*	1070	585	485	13.84	7.0			
	18	1105	840	265	7.56	7.0			
	19*	1025	310	715	20.40	11.0			
	20	1020	425	595	16.98	11.5			
	21	1000	430	570	16.27	10.3			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

Table 6

RECESSION DATA FROM TEST 1004

CALCULATION OR DATA SHEET PAGE OF

SERIAL NO. TIP-3
TEST 1004 - 11/12/81
POS. 1 - 35.05 Sec.

RECOVERY ENTHALPY - 451 Btu/lb
RECOVERY TEMPERATURE - 1420°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT^2-SEC)	R/Q MIL/BTU-FT^2		
CPR-488	1	1240	1004	236	6.73	5.45	1.23		
	2	1235	1045	190	5.42	5.50	.99		
	3	1240	1050	190	5.42	5.55	.97		
	4	1180	950	230	6.56	5.00	1.31		
	6	1240	990	250	7.13	6.20	1.15		
	8	1280	1072	208	5.93	5.50	1.08		
	9	1280	1072	208	5.93	5.50	1.08		
	10	1205	940	265	7.56	10.00	.76		
	11	1165	850	315	8.99	9.80	.91		
	12	1360	1100	260	7.42	6.30	1.18		
	13	1190	956	234	6.68	5.80	1.15		
	14	1235	986	249	7.10	5.35	1.33		
	15	1210	882	328	9.36	9.90	.95		
	AVER.	1235	992	244	6.96	6.60	1.05		
BX-250	5*	1255	860	395	11.27	6.00			
	7*	1205	725	480	13.69	9.90			
	16*	1280	700	580	16.55	7.40			
	17*	1240	905	335	9.56	5.50			
	18	1250	820	430	12.27	6.54			
	19*	1205	455	750	21.40	9.95			
	20*	1205	750	455	12.98	9.90			
	21	1200	710	490	13.98	9.90			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

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Table 7

RECESSION DATA FROM TEST 1005

CALCULATION OR DATA SHEET PAGE OF

SERIAL NO. TIP-4
TEST 1005 - 11/12/81
POS. 1 - 35.05 Sec.

RECOVERY ENTHALPY - 451 Btu/lb
RECOVERY TEMPERATURE - 1420°F

	POS. #	PRETEST THICK. (MIL)	POSTTEST THICK. (MIL)	Δ THICK. (MIL)	$\dot{r}$ (MIL/SEC)	$\dot{q}$ (BTU/FT²-SEC)	R/Q MIL/BTU-FT²		
CPR-488	1	990	845	145	4.14	5.45	.76		
	2	1065	892	173	4.94	5.50	.90		
	3	1075	893	182	5.19	5.55	.94		
	4	1005	966	39	1.11	5.00	.22		
	6	1060	815	245	6.99	6.20	1.12		
	8	1065	965	100	2.85	5.50	.51		
	9	1040	945	95	2.71	5.50	.49		
	10	995	700	295	8.42	10.00	.8		
	11	995	672	323	9.22	9.80	.94		
	12	985	825	160	4.56	6.30	.72		
	13	1025	950	75	2.14	5.80	.37		
	14	1105	844	261	7.45	5.35	1.39		
	15	990	705	285	8.13	9.90	.82		
	AVER.	1030	847	183	5.22	6.60	.79		
BX-250	5*	1005	640	365	10.41	6.00			
	7*	940	510	430	12.27	9.90			
	16*	960	670	290	8.27	7.40			
	17*	1000	675	325	9.27	5.50			
	18*	1035	865	170	4.85	6.54			
	19*	950	260	690	19.69	9.95			
	20*	930	500	430	12.27	9.90			
	21	935	490	445	12.70	9.90			

*LOCATIONS WHERE MATERIAL DID NOT RECEDE BELOW BX250 PLUG

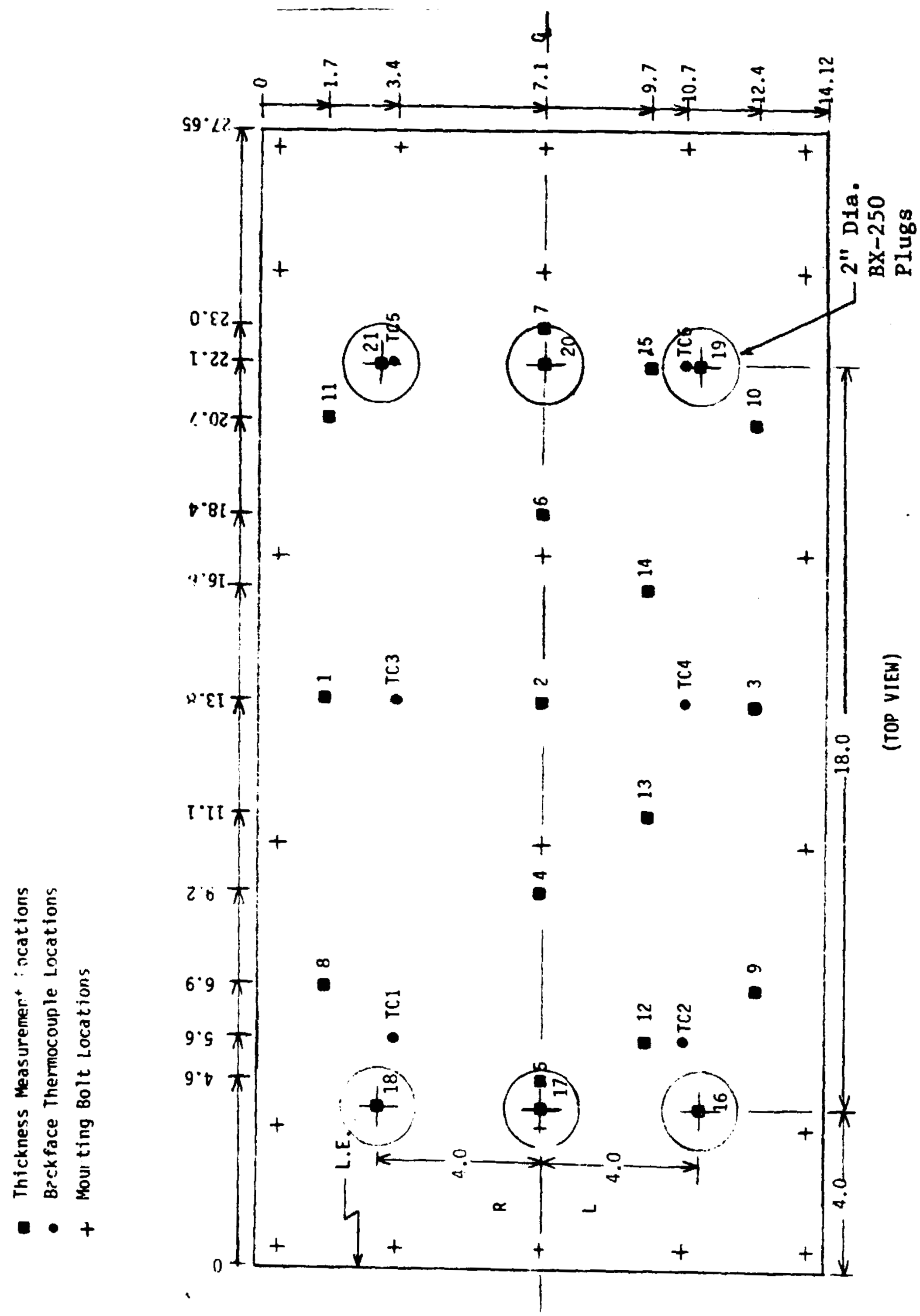


Fig. 1 - Sketch Showing Layout of CPR-488 TIP Panels

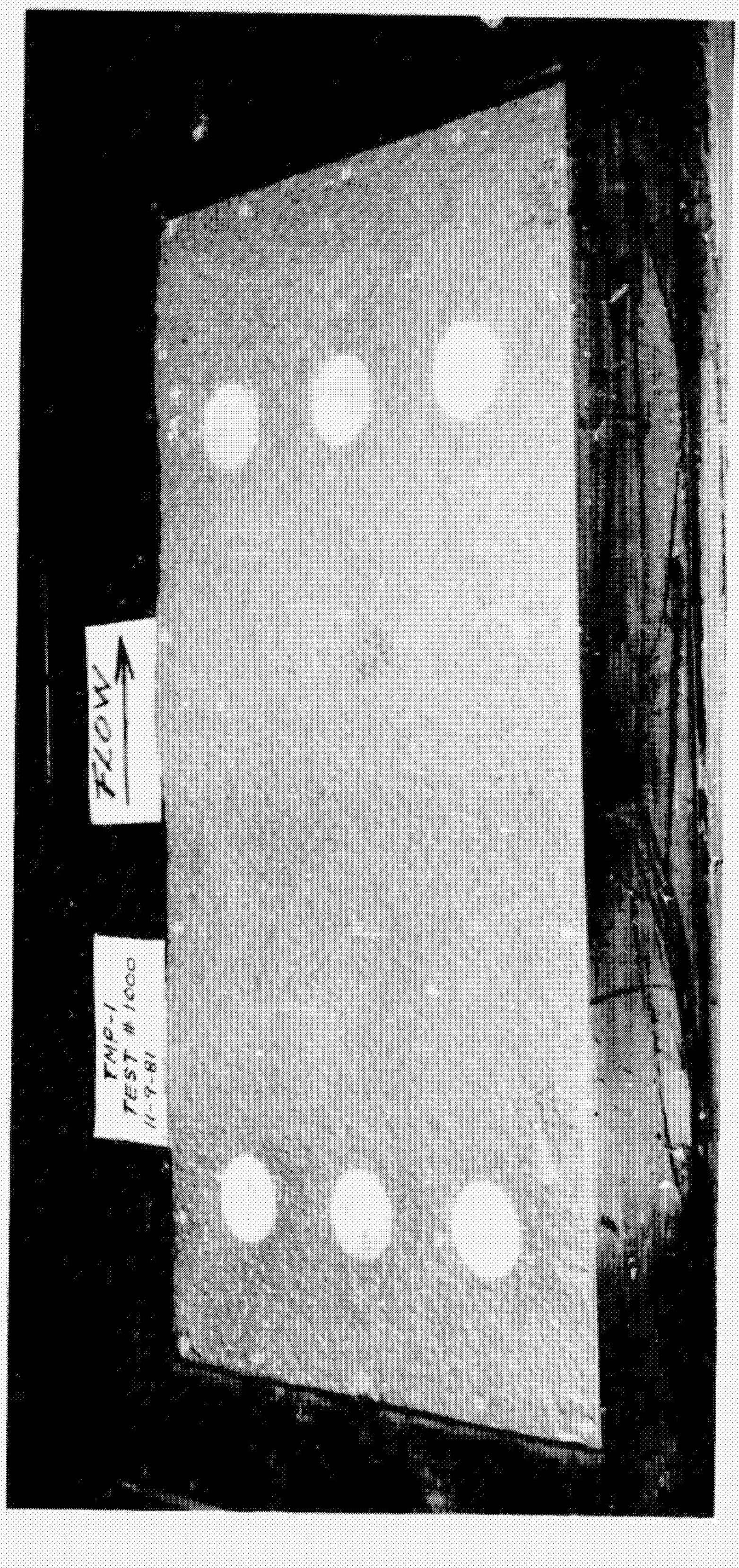


Fig. 2 - Pretest Photo of Panel TIP-1

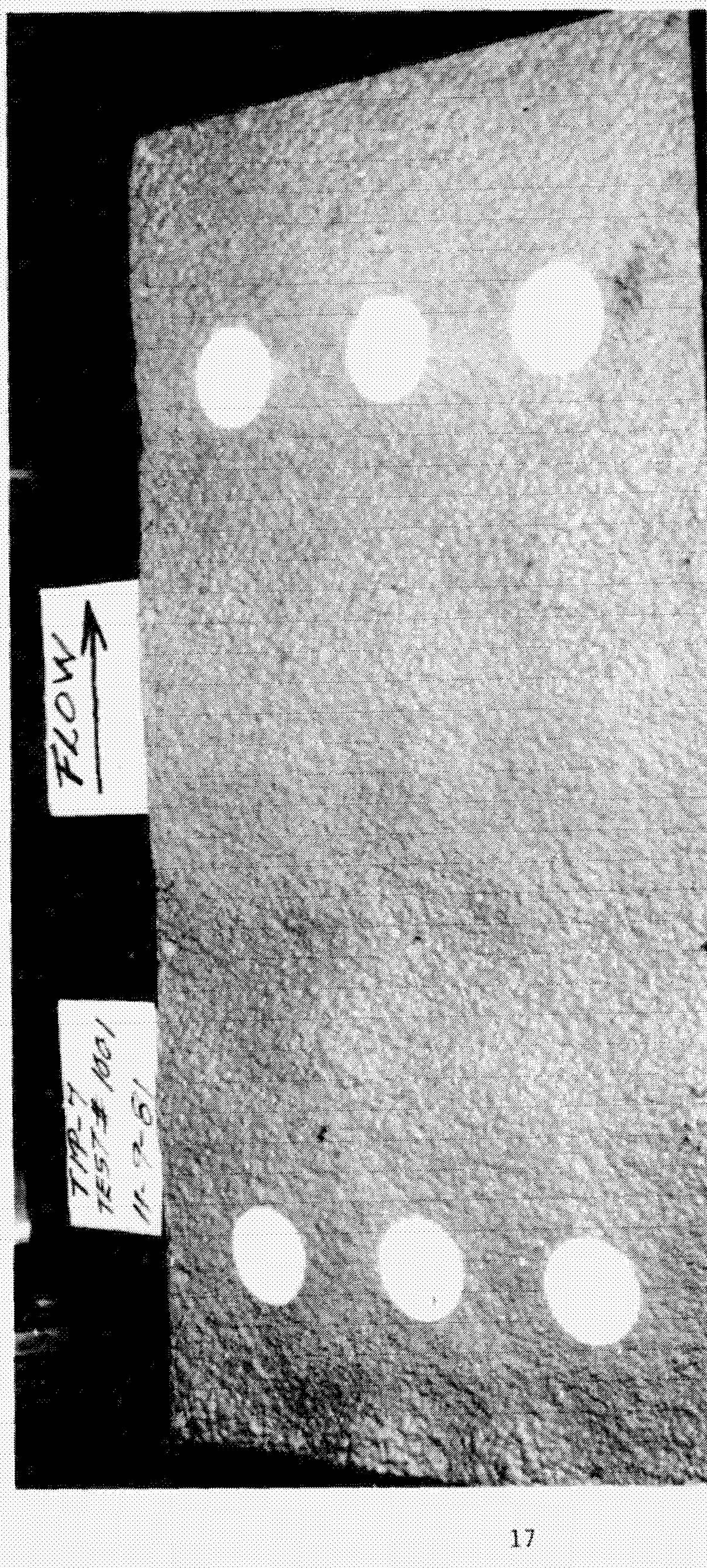


Fig. 3 - Pretest Photo of Panel TIP-7

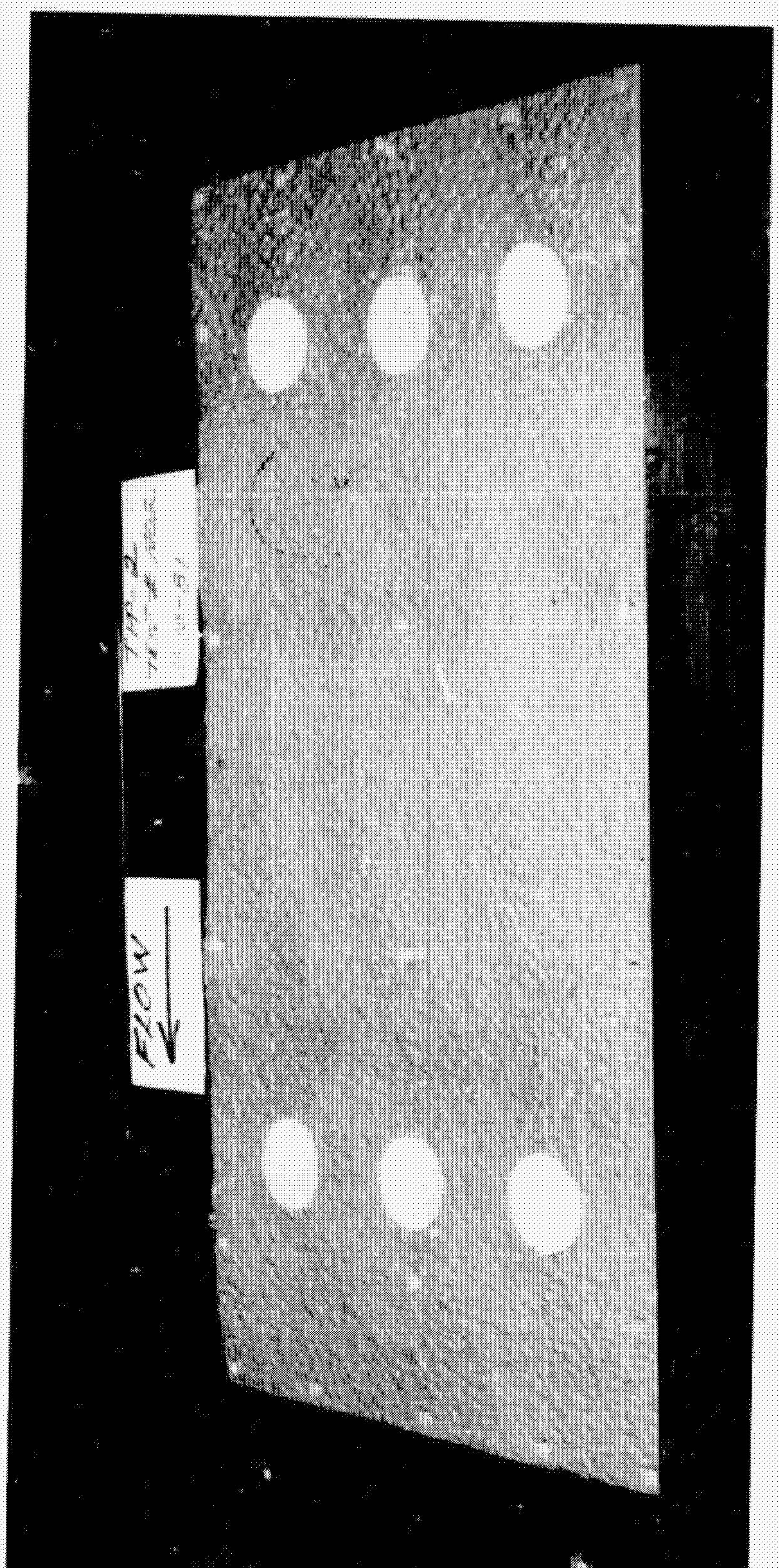


Fig. 4 - Pretest Photo of Panel TIP-2

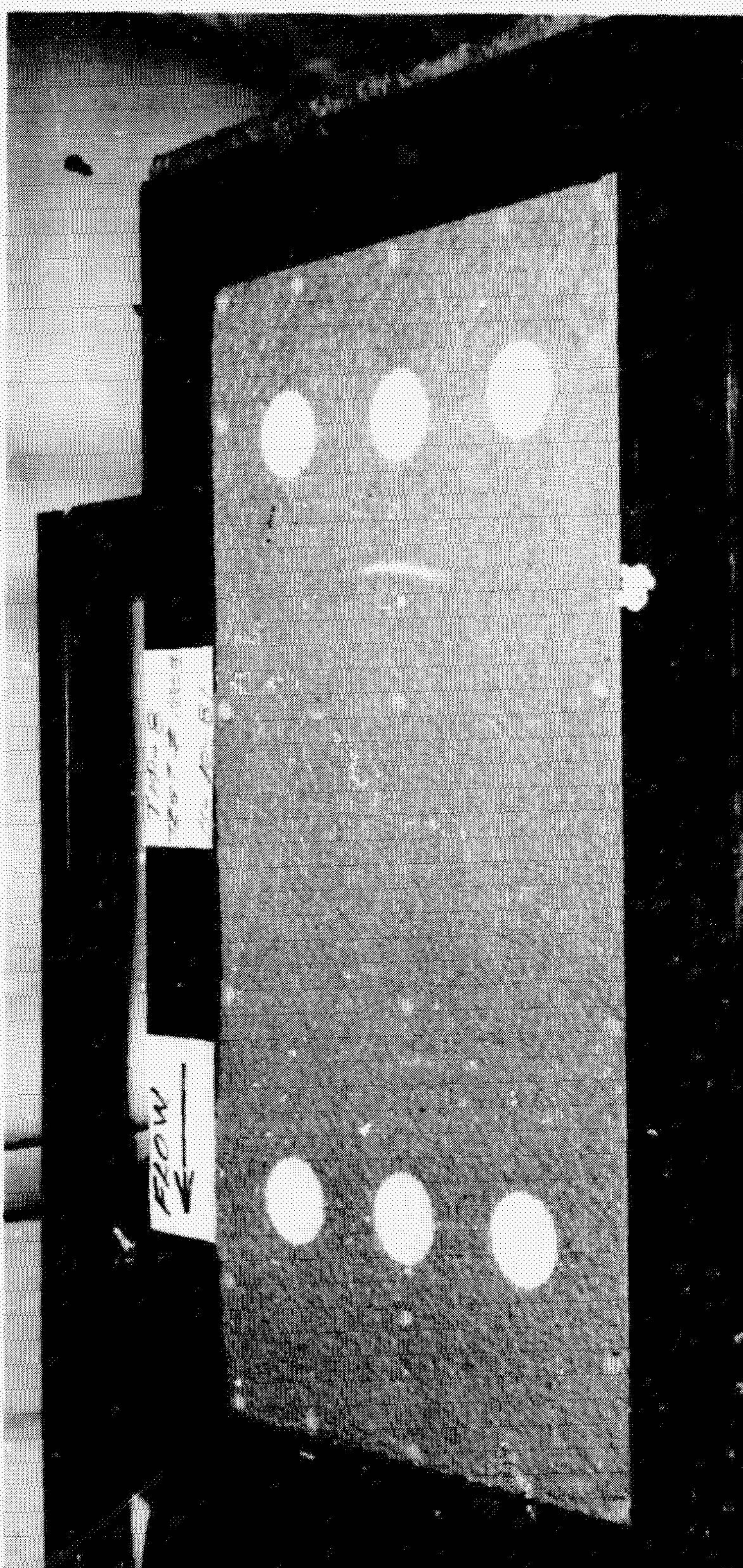


Fig. 5 - Pretest Photo of Panel TIP-8

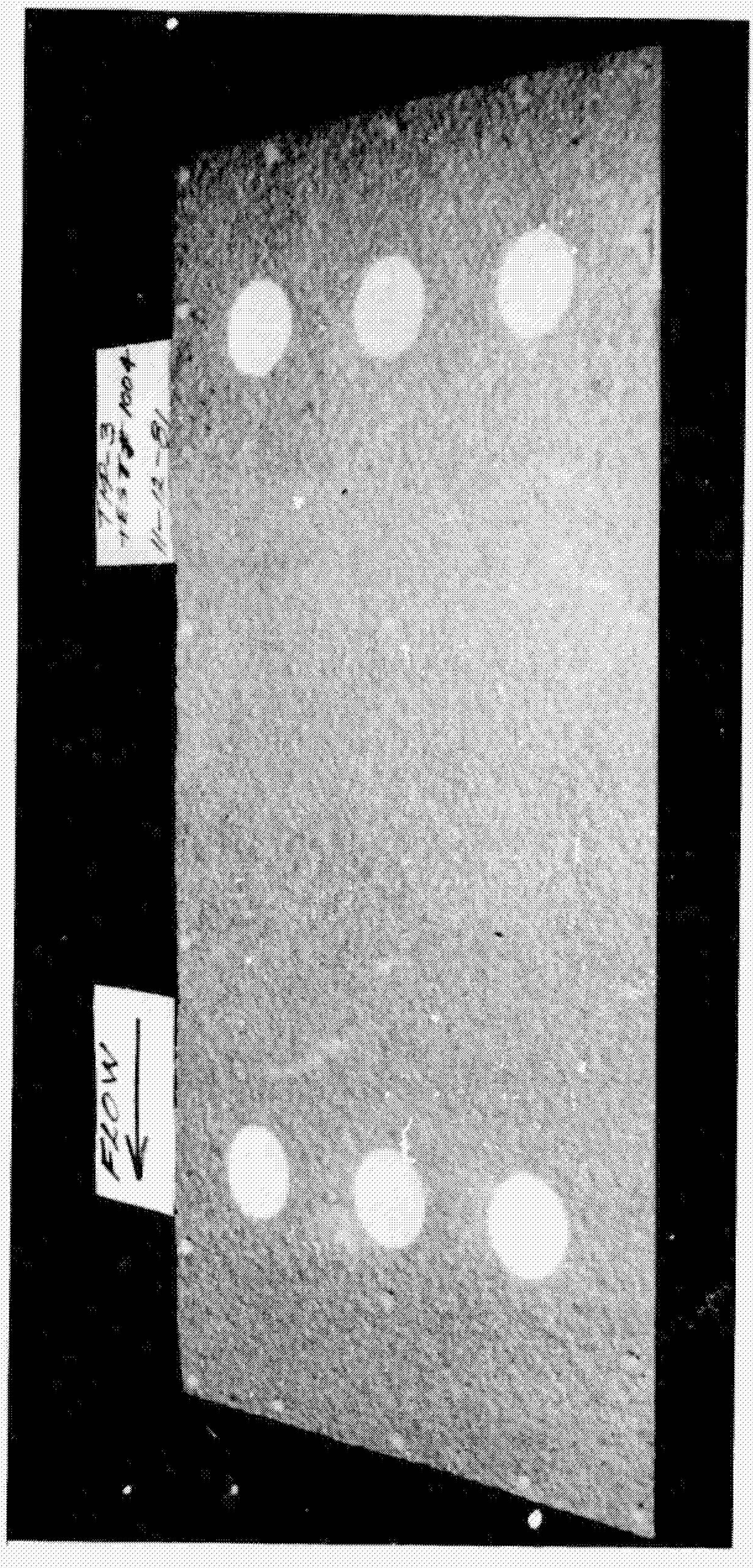


Fig. 6 – Pretest Photo of Panel TIP-3

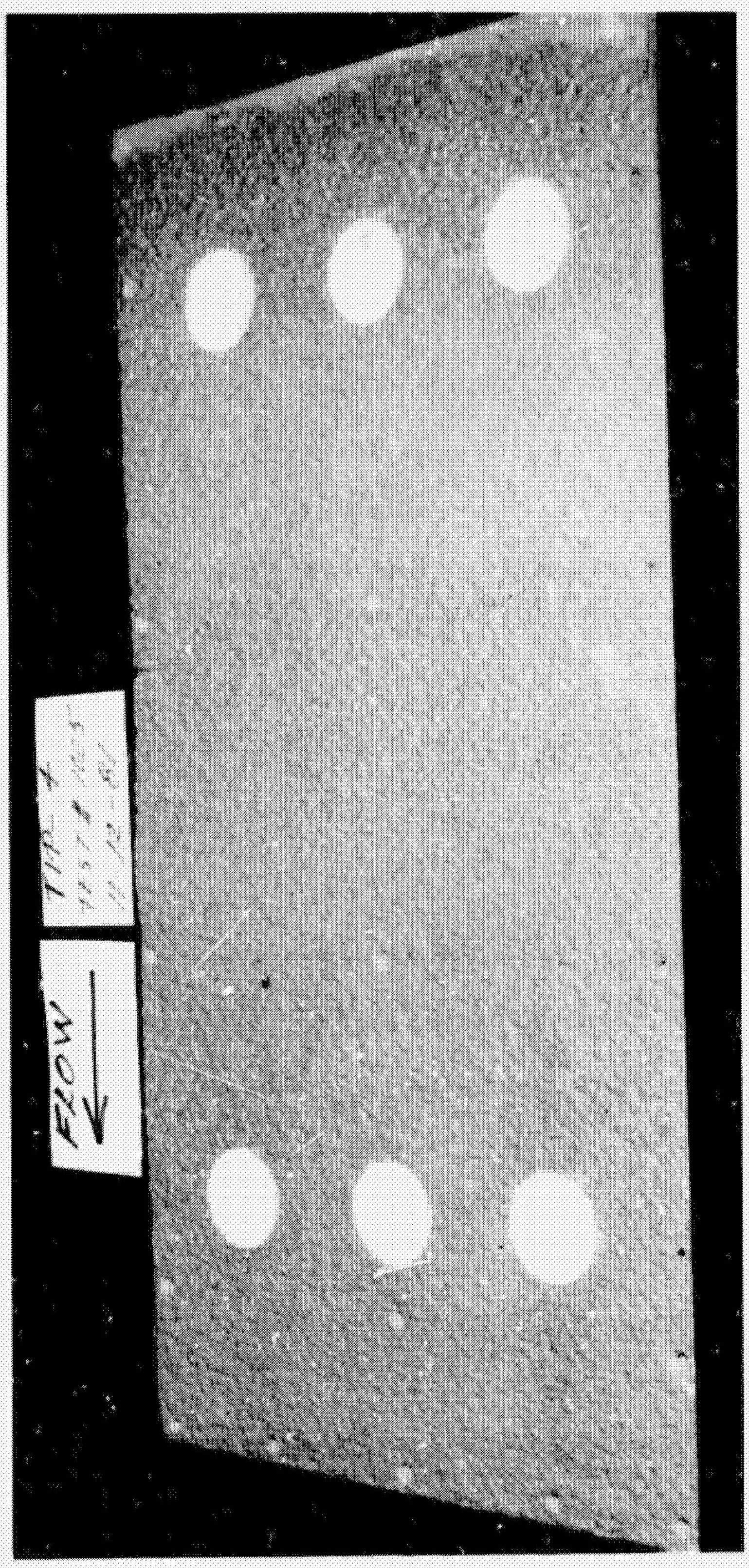
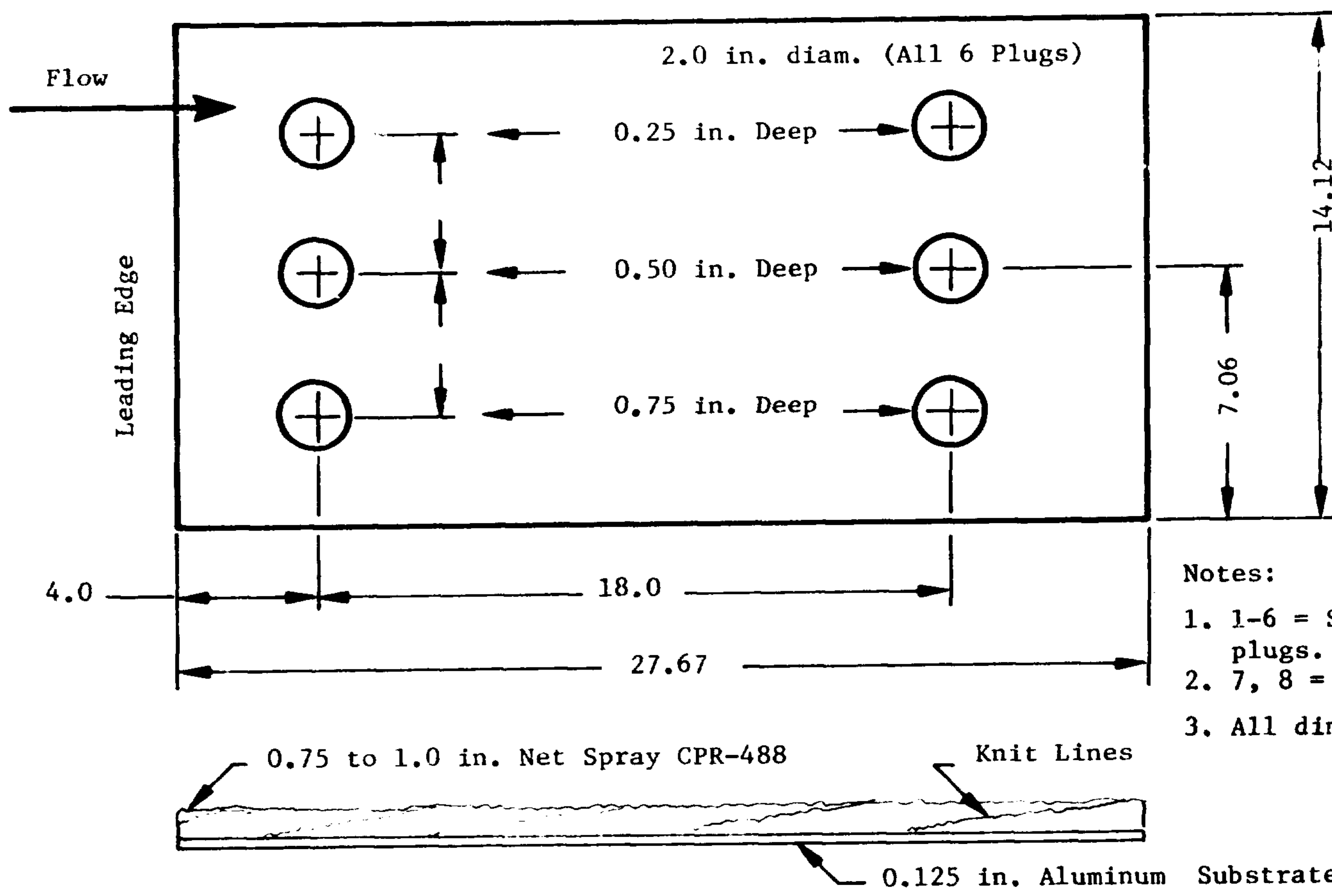


Fig. 7 - Pretest Photo of Panel TIP-4



Notes:

1. 1-6 = Standard BX-250 plugs.
2. 7, 8 = BX + TiO_2 plugs.
3. All dimensions in inches.

Fig. 8 - TIP Plug Thicknesses

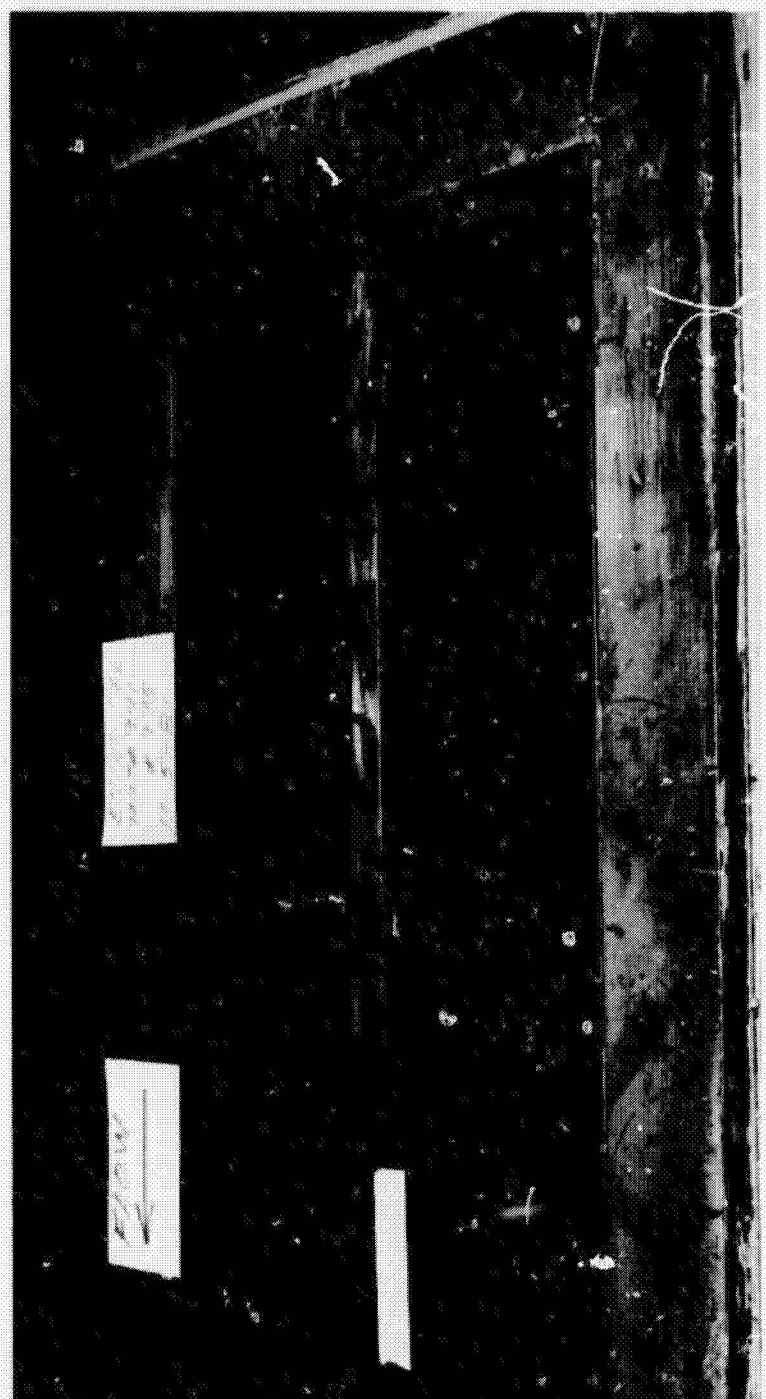
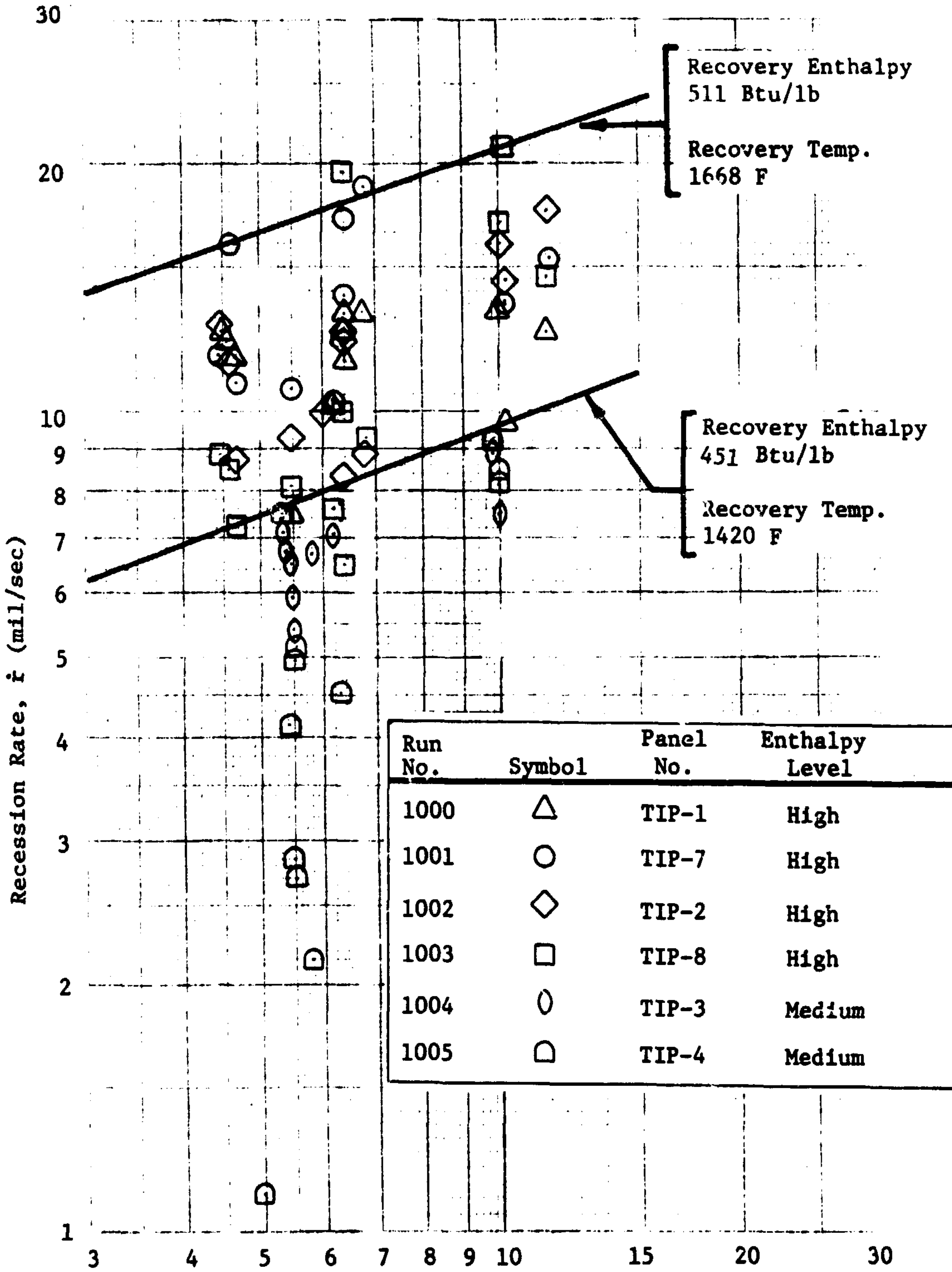


Fig. 9 - Heating Rate Cal Model



Run No.	Symbol	Panel No.	Enthalpy Level
1000	△	TIP-1	High
1001	○	TIP-7	High
1002	◇	TIP-2	High
1003	□	TIP-8	High
1004	0	TIP-3	Medium
1005	⌂	TIP-4	Medium

Fig. 10 - Recession Rate vs Heating Rate for CPR-488 Foam at Two Enthalpy Levels

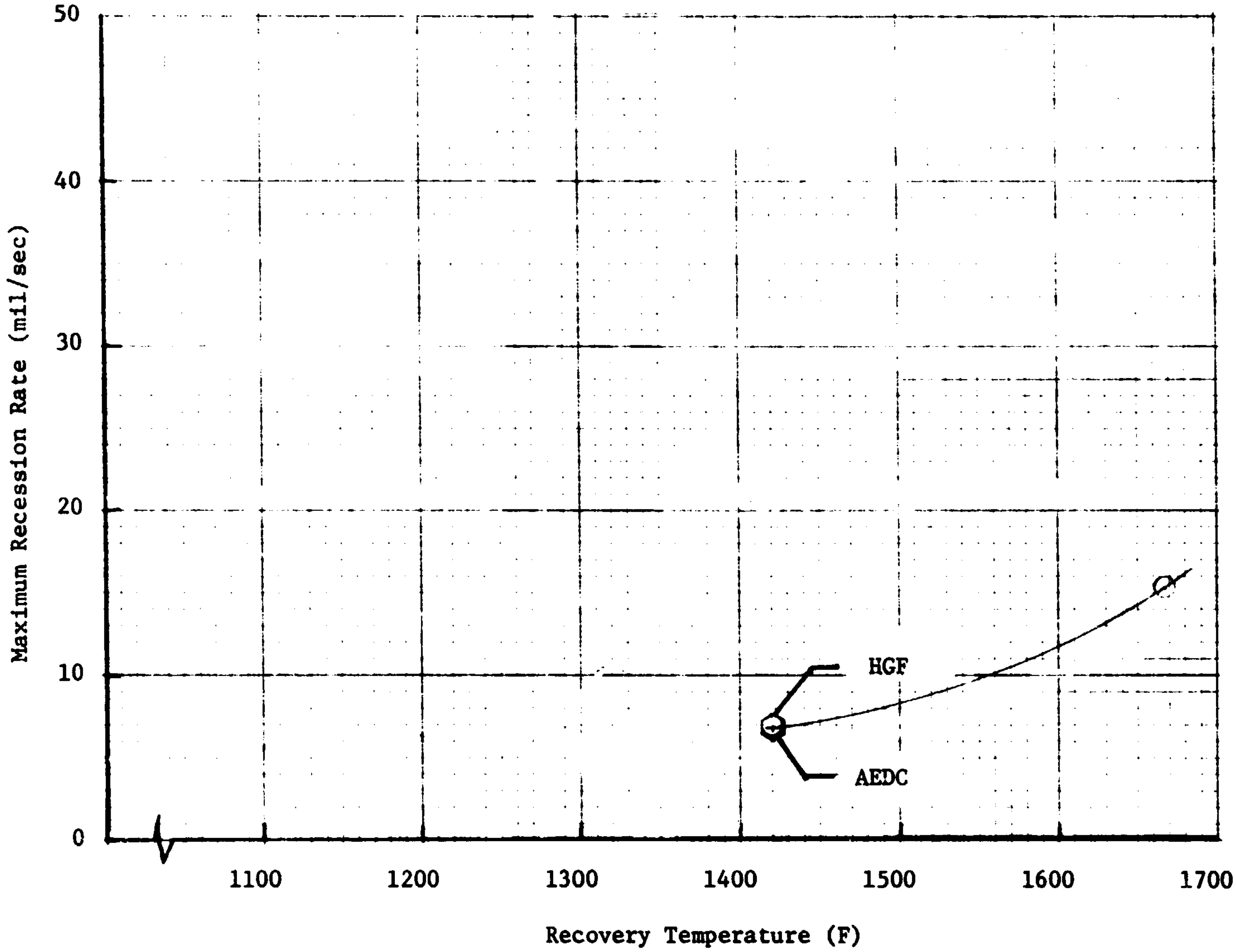


Fig. 11 - Maximum Recession Rate vs Recovery Temperature for a Constant Heating Rate of 4 Btu/ft^2-

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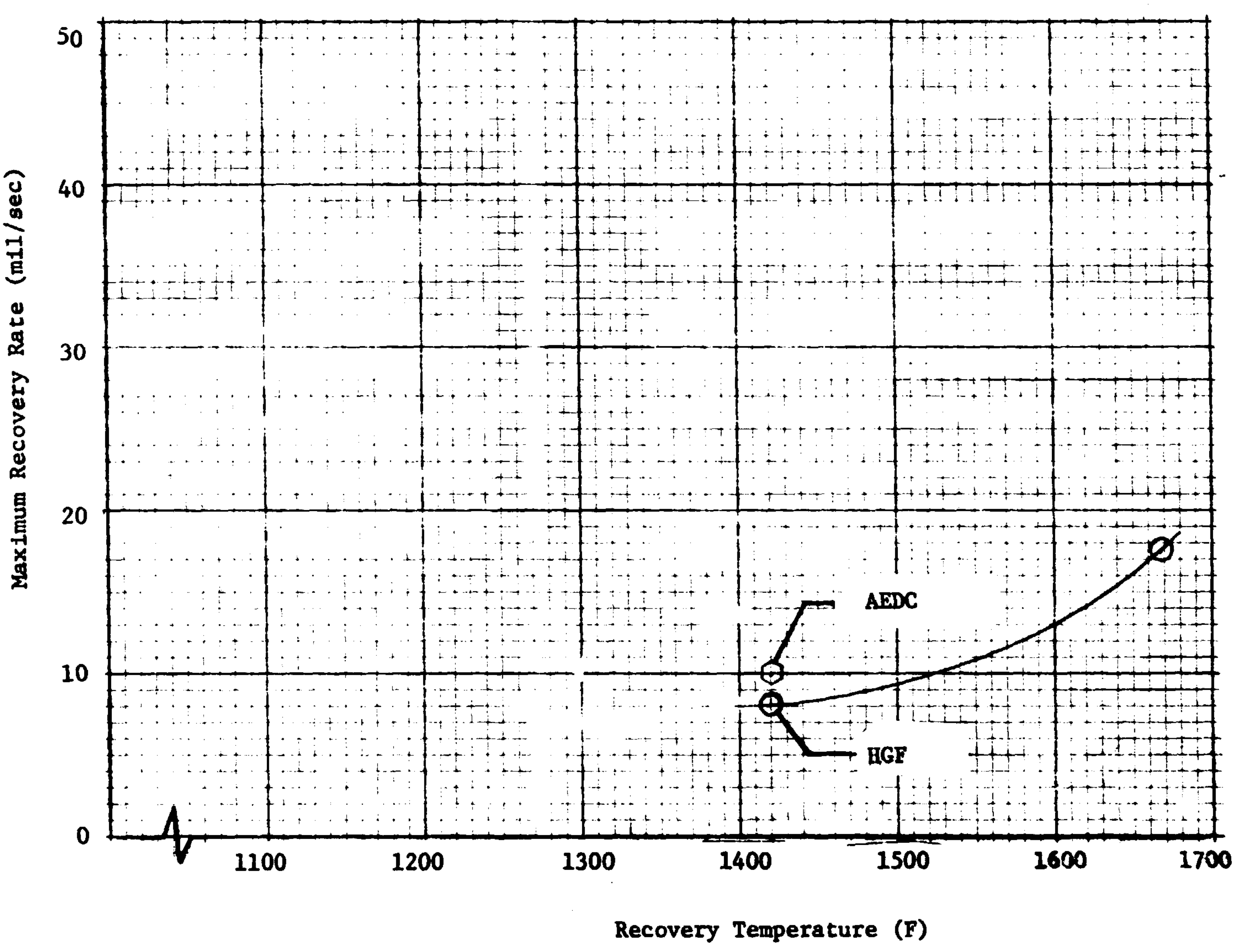

Fig. 12 - Maximum Recession Rate vs Recovery Temperature for a Constant Heating Rate of 6 Btu/ft^2-sec.

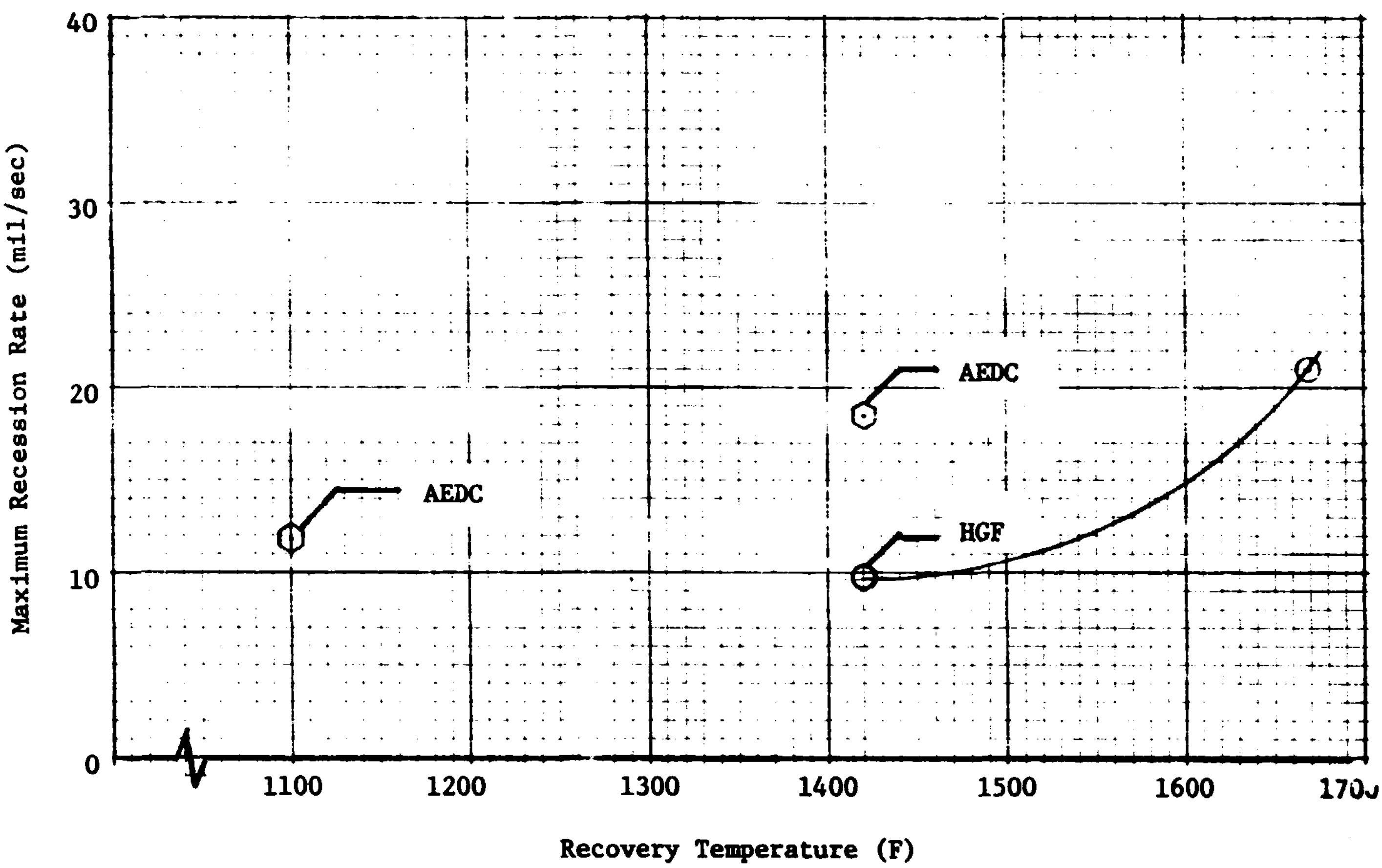

Fig. 13 - Maximum Recession Rate vs Recovery Temperature for a Constant Heating Rate of 10 Btu/ft^2-sec

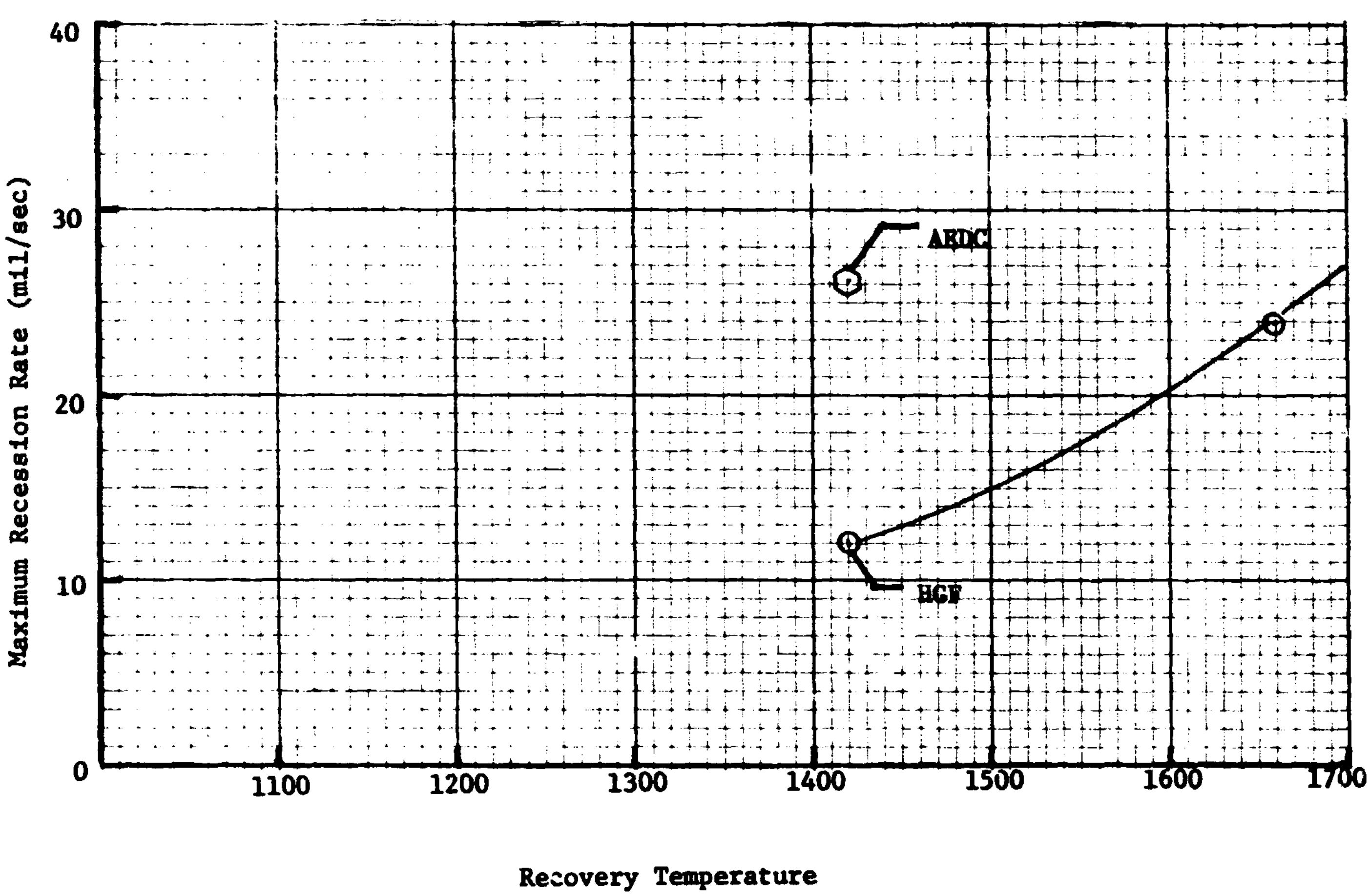

Fig. 14 - Maximum Recession Rate vs Recovery Temperature for a Constant Heating Rate of 15 Btu/ft^2-sec

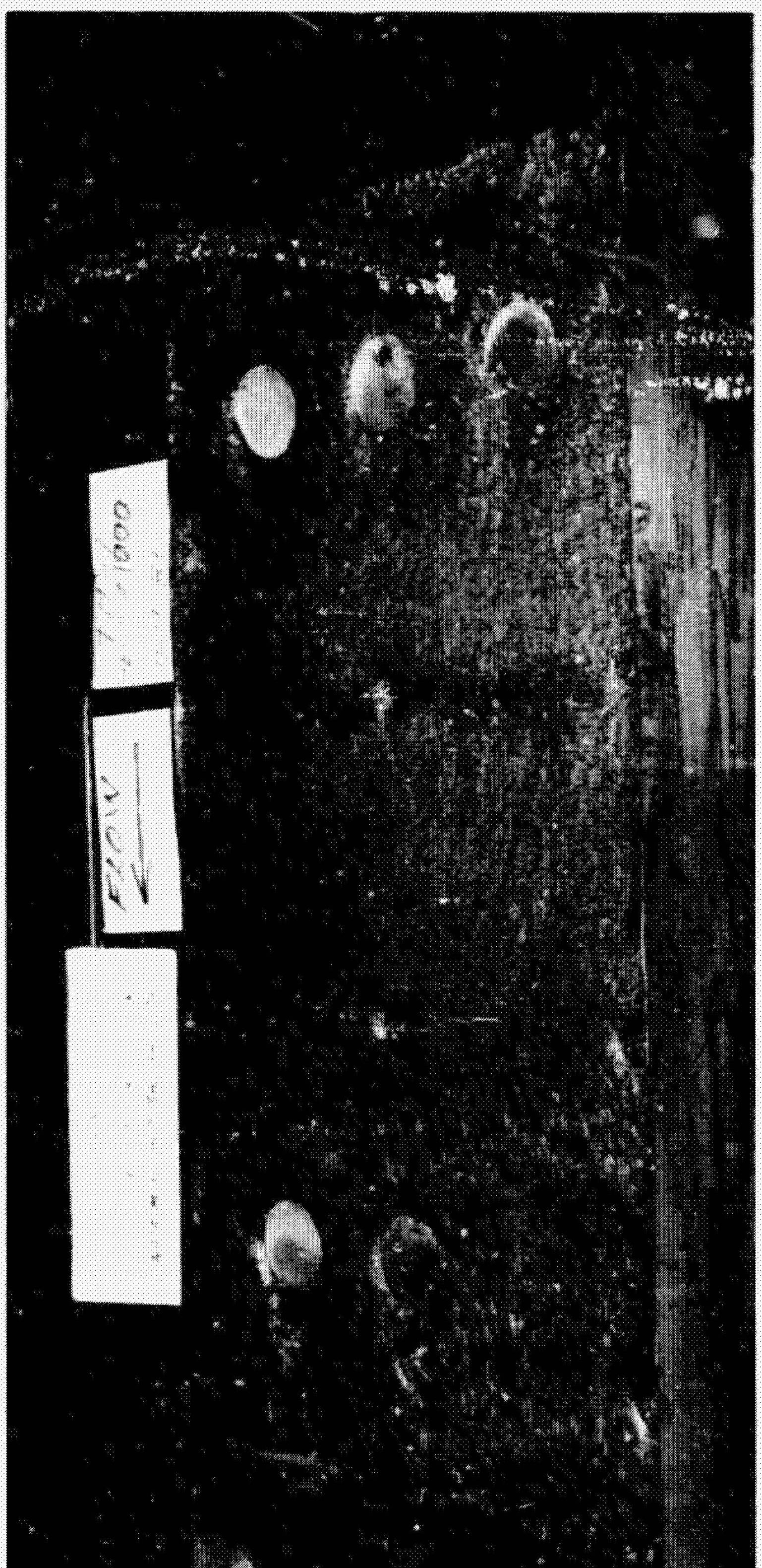

Fig. 15 - Post-Test Photo of Panel TIP-1

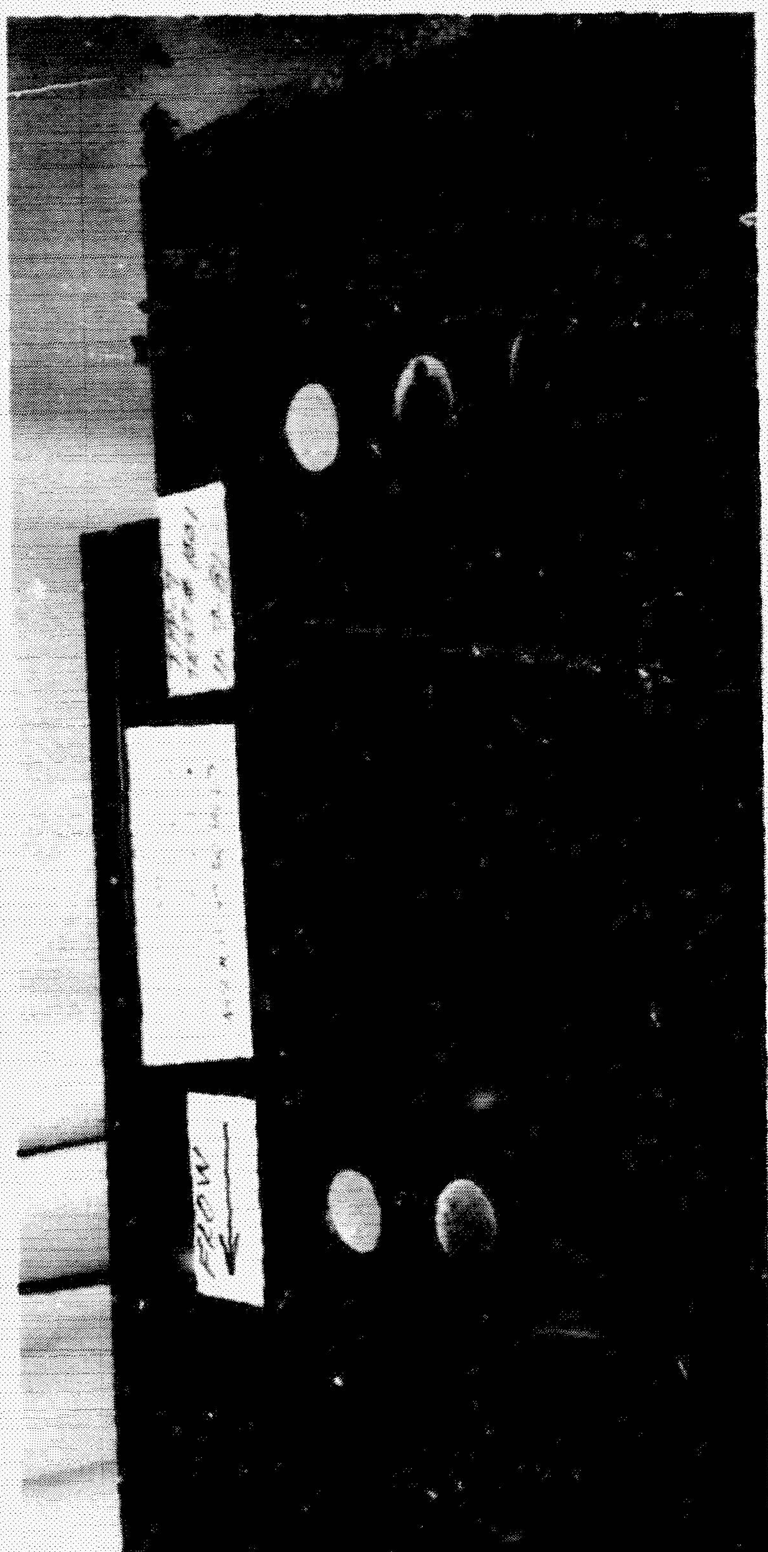

Fig. 16 - Post-Test Photo of Panel TIP-7 (BX-250 Plugs Had TiO_2 Added, Therefore are Lighter in Color)

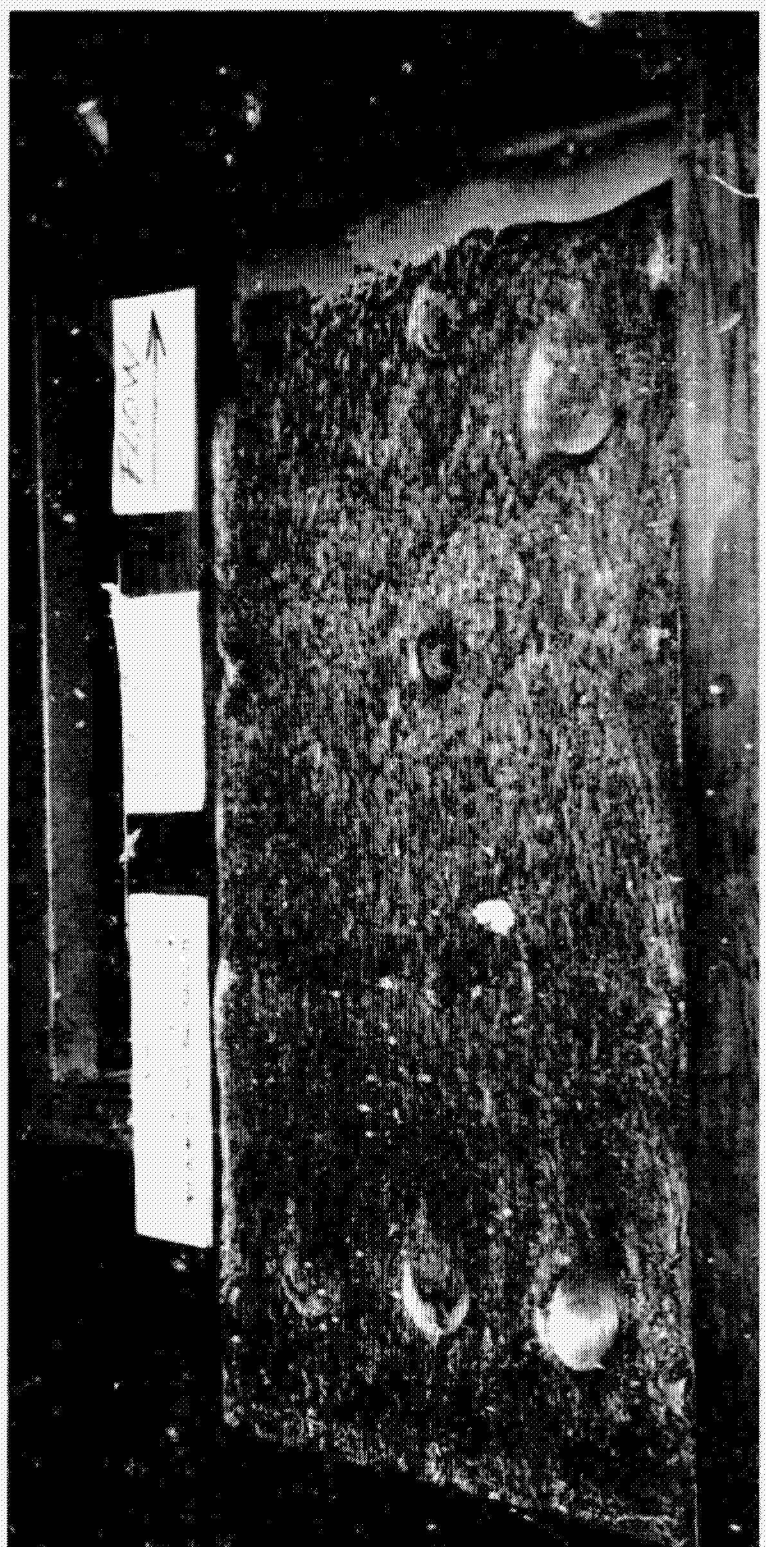

Fig. 17 - Post-Test Photo of Panel TIP-2

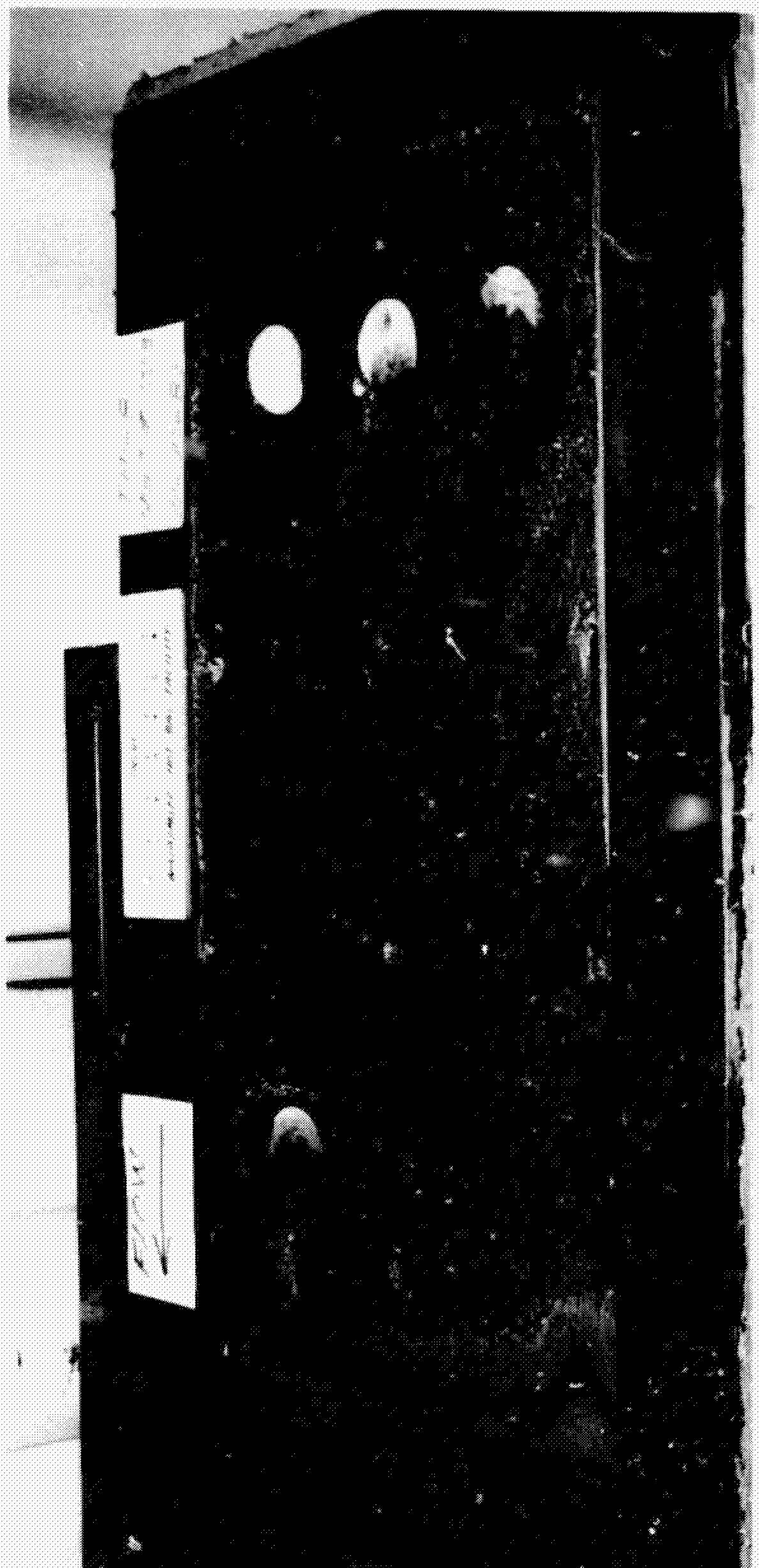

Fig. 18 - Post-Test Photo of Panel TIP-8, (BX-250 Plugs Had TiO_2 Added, Therefore are Lighter in Color)

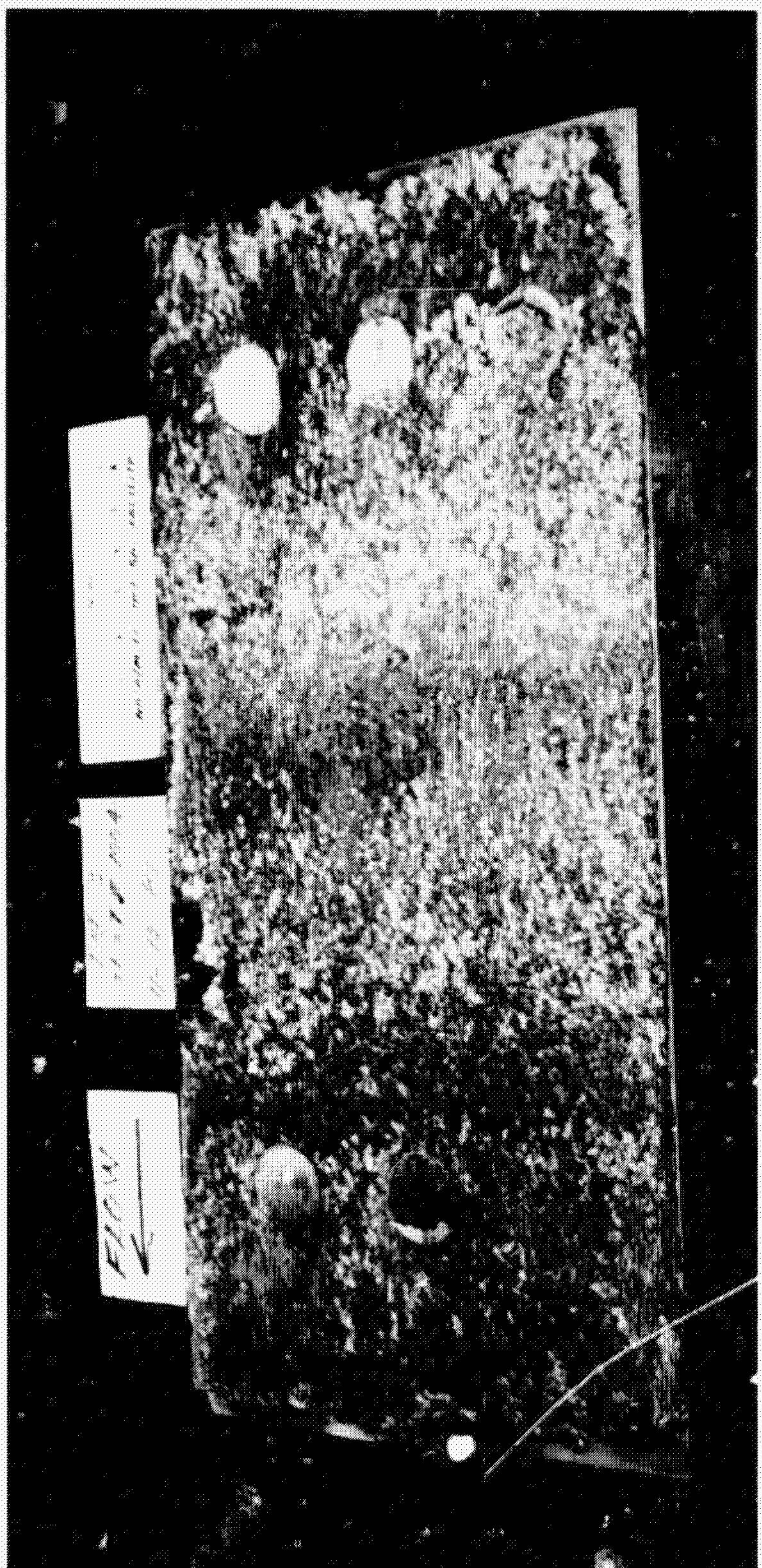

Fig. 19 - Post-Test Photo of Panel TIP-3 (Most of Char Blew Away During Rough Shutdown of HGF)

Fig. 20 - *Post-Test Photo of Panel TIP-4*